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THE RESULTS OF AFAMRL REMOTELY PILOTED VEHICLE (RPV) SIMULATION STUDIES VII AND VIII

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MAY 1981

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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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The AFAMRL RPV System Simulation and Research Program was originally initiated in response to RPV advanced system design requirements. Over time, the emphasis has shifted to basic research so that currently the program is used to develop simulation construction and research methodologies relating to conducting research on large systems. The two studies reported here relate specifically to issues of system simulation and modeling construction. The results of the seventh and the eighth RPV simulation studies (continued

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are reported herein. In RPV Study VII, the main interest was in the composition of three teams of five operators each: do independent teams whose individual members belong to one team perform differently from teams whose members are chosen from a limited pool of operators such that each operator performs on two teams. In RPV Study VIII, another aspect of team compostition was investigated: how is the performance of an individual operator reflected in the performance of a team and across teams of varying sizes. In both studies, the operators were highly experienced in the control of the simulated RPV system. Both studies employed scenarios requiring that support RPVs provide coverage for a set of weapon delivery/strike RPVs. The RPV system was assumed to operate in an environment where a radio frequency has to be shared by multiple users, so that a time slot for command and telemetry transmissions becomes available for RPV system use only on a periodic basis. The results of RPV Study VII indicated that average performance remained unchanged from independently constituted teams to pooled constituted teams. However, the variablity in terms of standard deviations of dependent measures was reduced. The results of RPV Study VIII indicated that operator-centered tasks are largely unaffected by team size, and that highly trained operators are unaffected by team size on the same tasks. Workload, in terms of the number of RPVs to be controlled, had an effect on performance by itself but had no differential effect over team sizes or operators.

PREFACE

Dr. Mills was responsible for the overall management of the AFAMRL RPV Systems Simulation Program. Mr. Aume was responsible for the technical operation of the program and for writing the report. Dr. P. T. Bapu of the University of Dayton Research Institute was responsible for data handling and analysis under contract F33615-77-C-0520. Lt. Colonel Joseph B. Birt was the monitor of the overall basic research program in the Human Engineering Division of the Air Force Aerospace Medical Research Laboratory (AFAMRL) and we are grateful for his support.

The authors also acknowledge the assistance of Mr. Timothy Reid and Mr. William Deleranko, University of Dayton. Each of these individuals has contributed substantially to the success of the AFAMRL RPV Systems Simulation Program being conducted in this Laboratory.

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1.0 INTRODUCTION

1.1.0 The AFAMRL RPV Systems Simulation and Research Program was initiated in April 1973 in response to requirements for support of the design of the man-machine/environment interface of Air Force advanced RPV systems capable of simultaneous control of large sets of RPVs. As such, its major objectives were of the applied type such as evaluating alternative design configurations, assessing RPV systems effectiveness, providing engineering data for systems design. While the results of the current study can still be used for such applications as systems design, the emphasis has shifted over time to provide basic research support to AFAMRL's Systems Technology Development Program and a new set of objectives has emerged:

1.1.1 Develop a team-in-the-loop computer simulation capable of emulating a real-world system. Such a system then becomes a laboratory instrument or "guinea pig" for experimental manipulation and observation.

1.1.2 Develop a methodology of data analysis and interpretation which is valid and useful for the study of large-scale systems.

1.1.3 Conduct exploratory studies to provide insight into the behavior of systems and the construction of simulations and models of systems.

1.2.0 The two studies reported herein were designed to address two issues in the area of systems modeling/simulation construction. The ultimate objective of work in this area is to provide guidelines pertaining to how one goes about constructing a model or simulation of a complex system. (Note: The term "system" that is being used here is intended to include human, hardware, and environmental components that are interactive over time.)

1.2.1 The first study, RPV Study VII, was designed to explore an issue of team (i.e., crew) composition: Do teams perform differently depending upon whether or not they are independent of one another in terms of operator involvement? Teams of operators may be assumed to be independent of each other if no individual operator is a member of more than one team (i.e., independently constituted teams). However, suppose an investigator must construct a set of teams from a limited pool of available operators by random assignment, forcing a situation where individual operators are members of more than one team (i.e., pooled constituted teams). Such a case is not unrealistic when one considers a research program involving a team-in-the-loop system simulation and the following primary constraints: (a) limited funds to support a large number of teams, (b) limited long-term availability of operators who are experienced (have been trained) with the complex tasks of a system simulation, and (c) limited management (e.g., scheduling) flexibility such that the greater the number of operators employed, the greater are the management problems. Thus, in many cases, it might be desirable to organize teams from a small, well-trained pool of operators that can more easily be managed over a long period of time. However, doing so also means that team performance will be intercorrelated in some manner and will violate the assumption of independence among teams for statistical analysis and generalization purposes. Specifically, then, RPV Study VII provides a comparison between system simulation performance obtained from independently constituted teams (three, 5-person teams) and performance obtained from pooled constituted teams (three, 5-person teams in which operators were members of two teams).

1.2.2 The second study, RPV Study VIII, was also designed to explore issues of team composition: (a) Does an operator perform differently as a function of team size, and (b) does team performance vary with team size? The first issue can be stated differently. RPV Study VIII provided data on the existence or nonexistence of transfer functions between the performance of operators working alone and the performance of the same operators on team of varying sizes. The importance of this first issue may not be immediately obvious. In constructing models and fast-time simulations of systems, one is generally confronted with trying to obtain data that are relevant to teams or multi-operator performance. However, the literature provides very little of these kinds of data. Instead, most of the literature contain reports of studies of individual subject performance (or performance obtained by collapsing over individuals). It is also true that actually developing a literature data base pertaining to all types of team sizes and situations would be quite impossible. It has been generally assumed that one or more transfer functions exist between single and multiple operator performance as well as between teams of various sizes. If this were found to be true, it would be of considerable value to systems model and fast time simulation builders.

1.3.0 This technical report summarizes the data of the seventh and eighth RPV systems simulation studies (RPV Study VII and RPV Study VIII) employing the AFAMRL RPV System Simulation Test Bed.

2.0 AFAMRL RPV SYSTEM SIMULATION TEST BED

2.1.0 RPV Study VII and VIII employed the AFAMRL RPV Systems Simulation Test Bed. The simulation incorporates a large number of the parameters of a postulated real-world RPV system. The simulation employs four En Route/Return Phase operators and one Terminal Phase Pilot operator (henceforth referred to as Pilot). Each En Route/Return operator monitors and operates a computer graphics terminal (IBM 2250) comprised of a graphic display (Cathode Ray Tube, CRT), alphanumeric keyboard, light pen, a programmable function keyboard, and a small panel for hand-over actions. The pilot operates a pilot station comprised of basic flight instruments, a joystick for controlling a video camera over a terrain model, and a closed circuit TV monitor. The simulation is executed in real-time and permits simultaneous control of up to 35 simulated RPVs.

2.2.0 Figure 1 is a schematic layout of the simulation facility as it was configured for these studies. Note that the video camera can be controlled either manually in a continuous control mode or it can be positioned by the computer.

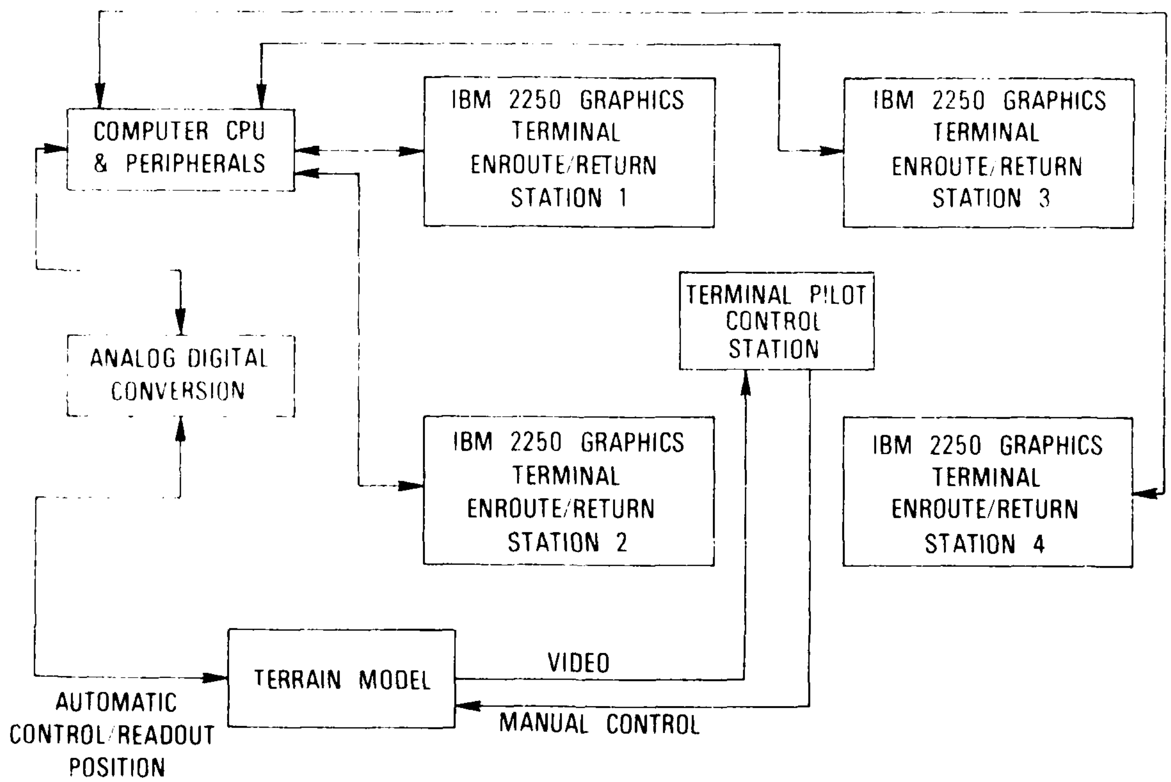

Figure 1. HUMAN ENGINEERING SYSTEMS SIMULATOR FACILITY CONFIGURATION

2.3.0 The RPVs are presumed to be capable of operating in two modes: first, the flight-path-follow (FPF) mode and second, the continuous control (CC) mode. In the FPF mode, there is a set of geographical coordinate points stored in the memory of the simulated RPV and it flies through these points. This process is completely automatic and self-contained with control signals coming from the simulated on-board navigation system. In the CC mode, control signals are produced by the pilot and are transmitted by radio to the RPV. With video feedback available, this allows highly accurate guidance to the target.

2.4.0 The AFAMRL RPV systems simulation can be briefly characterized in terms of the major submodels that are dynamically interfaced in the simulation. These submodels are listed below.

2.4.1 Simulated RPV heading, altitude, and velocity flight parameters. The updating of the system status is automatic and occurs in discrete time increments (to be discussed later).

2.4.2 Three data links (Command, Position Reporting, and Video) for each simulated RPV and with interference parameters.

2.4.3 Simulated RPV fuel load and rate of usage as a function of velocity and altitude.

2.4.4 Simulated RPV attrition probability parameters based on altitude and on the extent of (lateral) cross track deviation from the programmed flight plan.

2.4.5 Simulated RPV subsystem reliability operating in real "operational" time in conjunction with a simulated RPV inventory.

2.4.6 Simulated RPV navigation system parameters for Inertial, Doppler, and Basic Dead Reckoning systems.

2.5.0 Specific and detailed displays and controls available in the simulation and operating procedures are described in "Remotely Piloted Vehicle (RPV) Simulation Program Instruction Manual." This manual is intended for operator instruction and generally interested persons. It is being continually expanded and updated, and therefore, remains in draft form. A copy can be obtained from AFAMRL/HEF, Wright-Patterson AFB, Ohio 45433.

2.6.0 En Route/Return operators are provided with displays (updated in real-time) showing for each RPV: RPV type (i.e., strike, electronic warfare, reconnaissance), a flight plan, a track signature and heading/velocity vector displayed according to reported position, expected times of arrivals (ETAs) to waypoints, status of command data link, command and actual velocity, command and actual altitude, fuel remaining, lateral distance of the RPV from flight plan, various alarm conditions, etc. Figure 2 depicts the general layout of information on the CRT: Flight paths and RPV track signatures in the large area *in the upper left*

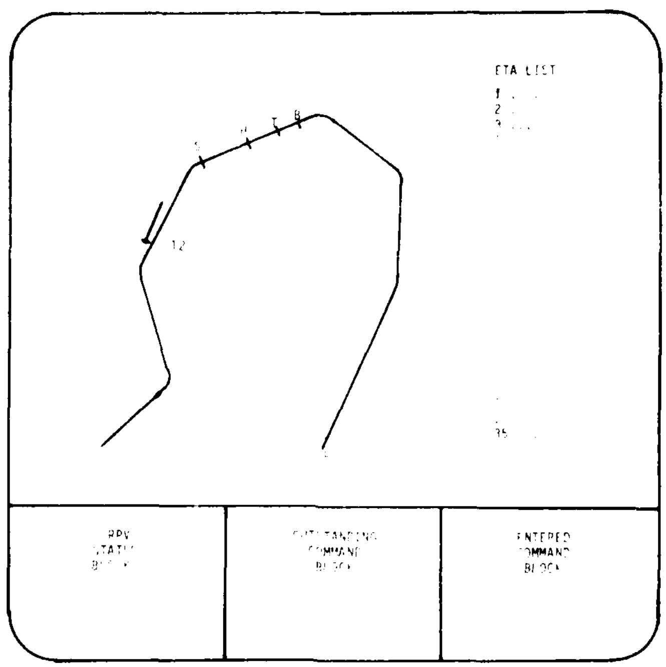

Figure 2. EN ROUTE-RETURN OPERATOR'S CRT DISPLAY LAYOUT

(S12 indicates strike RPV 12), a listing of RPV tail numbers and associated information down the right side of the display, a status information block in the lower left corner, and two other message blocks in the lower center and the lower right areas. Operators also have the capability to window (zooming) around an RPV at two display scaling levels. Each En Route/Return operator can make use of all control devices (i.e., light pen, alphanumeric keyboard, programmable function keyboard, and the hand-over switch panel).

3.0 RPV MISSION SCENARIO PARAMTERS

3.1.0 RPV Study II (Mills et al., 1975a) employed a "generalized" mission scenario intended to establish base-line data and represented a cross-section of specific scenarios in that it contained system task elements expected to be present in most real-world RPV missions. RPV Study III (Mills et al, 1975c) employed a slightly more specialized mission scenario assuming that a limited set of support RPVs (Electronic Warfare and Low Altitude Reconnaissance) would be available for coverage of a set of strike RPVs or manned aircraft. RPV Study IV (Aume et al., 1976) continued to use this type of mission scenario. RPV Study V (Aume et al., 1977) and RPV Study VI (unpublished) used equal numbers of Strike, Electronic Warfare, and Low Reconnaissance RPVs, and required that the maximum number of Electronic Warfare RPVs be used to provide coverage to each Strike RPV. RPV Study VII continued to use this scenario. RPV Study VIII used an equal number of Strike and Electronic Warfare RPVs (Low Altitude Reconnaissance RPVs were not used) and required coverage by the maximum number of EW RPVs.

3.2.0 The parameters of the RPV mission scenario for RPV Studies VII and VIII are listed below. (The specific differences in scenarios for the two studies are relatively unimportant. The changes were made principally because of management considerations.)

3.2.1 RPV Launch and recovery phases are assumed to occur "outside" the simulation. RPVs are launched from one of three launch points in RPV Study VII and from two launch points in RPV Study VIII, and all are recovered at one point.

3.2.2 Each RPV has its own preprogrammed flight plan that is assumed to be stored both in the Drone Control Facility and the RPV computers.

3.2.3 Each flight plan is assumed to be optimal with respect to terrain and defenses. Thus, the Mission Planning subsystem is also assumed to be outside the simulation.

3.2.4 Each RPV is designated one of three mission types: Strike (Weapons Delivery), EW (Electronic Warfare), and Low Recce (Low Altitude Reconnaissance).

3.2.5 A round trip of approximately 300 NM per RPV is simulated, with the center of the target area located 150 NM from the launch insertion and recovery coordinates. Strike and Low Recce RPVs held quite closely to their path lengths. EW RPVs, due to repeated passes over targets, traveled considerably farther than the preprogrammed path length.

3.2.6 Each RPV has an initial command velocity of 350 knots and a command altitude of 200 feet. Both velocity and altitude are variable at the operator's discretion: Velocity between 300 and 400 knots and altitude between 0 and 10,000 feet.

3.2.7 The RPVs are launched according to type. The group of EW RPVs are launched first on 15-second intervals. These are followed by the

Low Recce (RPV Study VII only), also on 15-second intervals. The Strike Group is launched last on 3-minute intervals. The total number of vehicles is parameteric and is determined prior to each mission, there being an equal number of vehicles in each group.

3.2.8 There was a task requirement that each Strike, EW, and Low Recce group must be time-phased (coordinated arrivals) to target. Time-phasing is such that as many EW RPVs as possible must be within a 5 NM radius of the target assigned to the Strike and (in RPV Study VII only) a single Low Recce must follow the Strike vehicle after 2 minutes (simulating BDA). These coordination requirements are discussed in paragraph 5.6.1.

3.2.9 Each Strike flight plan has a redesignated waypoint S for cueing the start of hand-off procedures. Next comes the hand-off (H) waypoint at which the vehicle "enters the target area" and the pilot can acquire continuous control over it as well as receive TV returns from it. In addition, each Strike flight plan has a designated Target (T, one of three targets), Hand-Back (B), and Recovery (R) coordinates.

3.2.10 In the RPV Studies VII and VIII scenarios, the EW flight plans are programmed through all three targets (labeled 1, 2, and 3). No other waypoints are designated on these flight plans (except the Recovery coordinate).

3.2.11 Prior to hand-off, an RPV is given a command to climb to an altitude of 3000 ft. For Strike RPVs, the small area on the terrain model also required a change in command velocity to 300 knots.

3.2.12 On Strike flight plans the distance from S to H is 10.0 NM; from H to T, the distance is 1.5 NM.

3.2.13 Each RPV is given just enough fuel to complete the round trip mission. Strike and Low Recce RPVs are assigned a fuel load of 2200 pounds. EW RPVs are assigned a load of 3880 pounds. (NOTE: These values may seem a bit unrealistic; however, the original simulation assumed an advanced, large tactical RPV of F4 size.)

3.2.14 RPV position reporting error was 525 ft range error and 0.6 milliradian azimuth error. The RPV lateral deviation alarm threshold values were fixed at 1000 ft.

3.2.15 The simulation included a function to smooth raw RPV position reporting data. The smoothing function essentially fits a statistical, best-fit flight path to position reports. (If more detail is desired, see the Instruction Manual noted in 2.4.0.)

3.2.16 The simulation included a function to perform automatic RPV heading correction based on smoothed position report data. The automatic correction is ordered for an RPV when the lateral deviation or cross track error is in excess of 1000 ft. The lateral deviation of an RPV is measured relative (perpendicular distance) to its stored flight plan. (See the Instruction Manual noted in 2.4.0 for more detail.)

3.2.17 Both of the above functions (3.2.15 and 3.2.16) are assumed to occur at the RPV Control Facility and <u>not</u> onboard the RPV. This "smarter" RPV system was initiated in RPV Study III and has been continued in all subsequent RPV studies.

3.3.0 Figure 3 depicts the profile of a typical scenario used in RPV Studies VII and VIII. In this figure, a group consisting of Strike and EW and (for RPV Study VII), Low Recce flight plans are shown. In this situation, the EW and Low Recce RPVs are to rendezvous with the Strike RPV at Target T. As one of the task requirements is to provide coverage by the maximum number of EW RPVs, these vehicles are orbited in the vicinity of the target (to avoid a cluttered figure, only one EW RPV

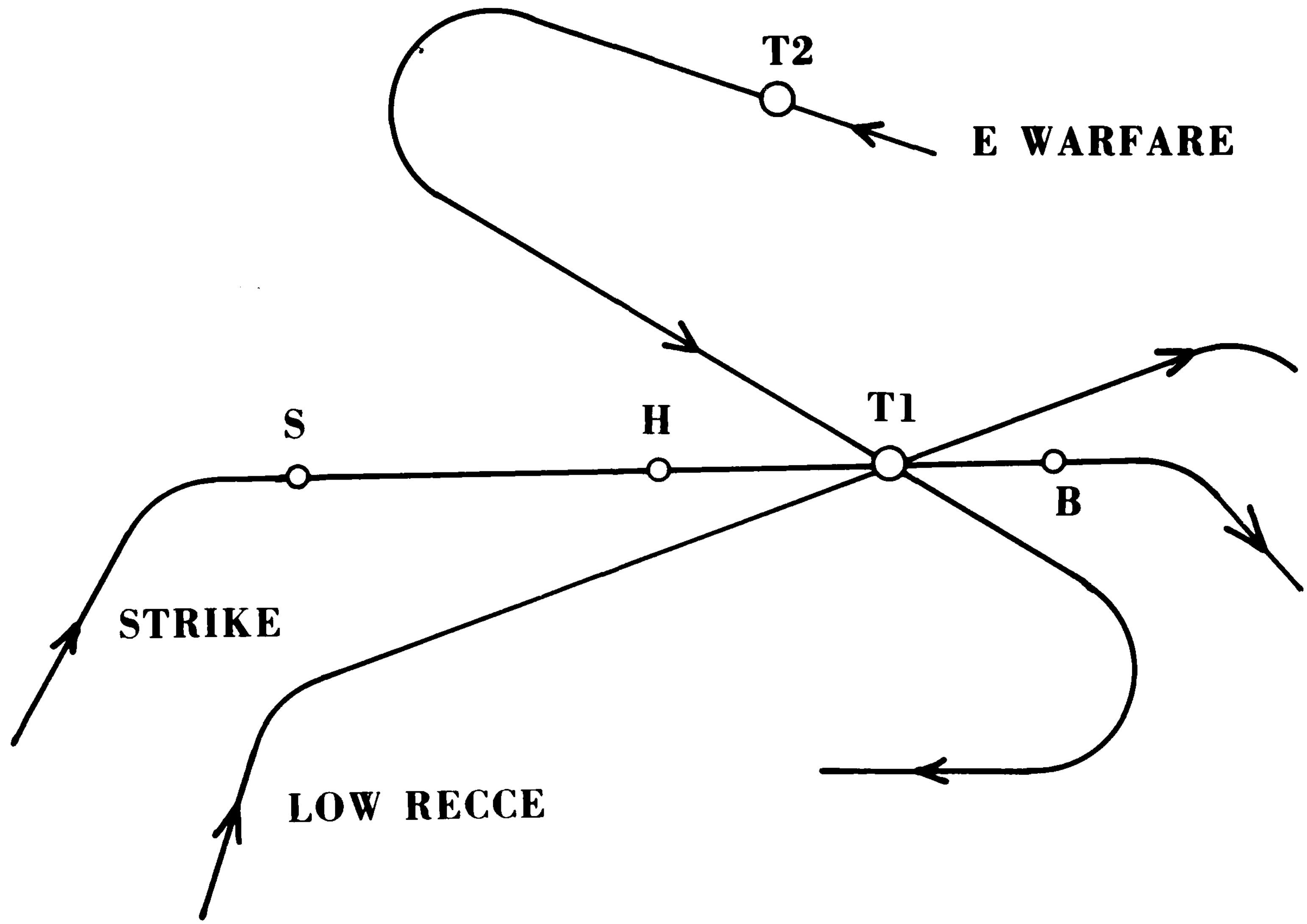

Figure 3. FLIGHT PATHS IN VICINITY OF TARGET

is shown). The EW RPV shown in the figure has previously covered a Strike RPV at Target T2. After covering Target T1, it is being turned back for additional coverage. To provide the necessary coverage at the targets, the operators are required to reroute (reprogram) EW RPVs such that the rendezvous with the incoming Strike RPV will occur according to time-phasing requirements (to be identified later).

4.0 CONTROL/DISPLAY PARAMETERS

4.1.0 Each En Route/Return operator station consists of an IBM 2250 Graphics CRT terminal. These terminals are equipped with a 12-inch CRT, light pen, alphanumeric keyboard, and a programmable function keyboard. A small panel of switches and lights has been added to each terminal for operator control during hand-offs.

4.2.0 The pilot's station is equipped with a joystick, basic flight instruments, and a TV monitor which alternately displays either imagery from the terrain during the final flight to target or information from one of the CRT terminals during other portions of a mission.

4.3.0 Each CRT has the capability to display flight plans, track signatures, etc., for up to 10 RPVs simultaneously. How many and which items of information are displayed are at the operator's discretion. RPV status parameters such as velocity, fuel remaining, RPV type, etc., are displayed for one individual RPV at a time. Other displayed parameters are ETA to the next designated waypoint, flight mode for each RPV in the system, and elapsed mission time.

4.4.0 Operators can "call" displays and can make changes to RPV flight parameters using the various control devices and can make changes to RPV flight parameters using the various control devices on the terminals.

For example, in the case of heading changes the operator can employ any one of the three window sizes (a 50x50 NM, a 100x100 NM which are centered on the RPV to be changed, and a 200x200 NM window which is centered on the entire geographical area). The operator then introduces a set of points (not to exceed 10) on the CRT face using the light pen. The point-to-point distances are also displayed. The heading changes always start from the current RPV position and must end on a "reconnect" point on the original flight path. This constitutes an "attempted" heading change. If the operator's prescribed points call for an impossibly tight turn according to the g-load value specified for the RPV, the computer rejects the set of points and sounds on audio alarm. The operator must then introduce a new set of points or the RPV continues unchanged. Valid heading change commands are transmitted over the simulated command data link to the onboard computer and the RPV proceeds to fly through the points prescribed in the command.

4.5.0 Each attempt to communicate an instruction to an RPV employs the command data link. The possible commands are altitude changes, velocity changes, navigation system changes, destruct, deploy chutes, and heading change. After a command is entered, it remains displayed in the "outstanding commands" block until it has been transmitted to the RPV.

4.6.0 The displayed position of each RPV is in the form of a track signature consisting of a heading/velocity vector and an ID number. The displayed position is computed by adding, vectorially, the position reporting system error, navigation system error, as compounded by operator error, to the true RPV position. Figure 2 shows a typical track signature for RPV No. 12, drawn considerably off-course, to make it clearly distinguishable.

5.0 OPERATOR RESPONSIBILITES AND PROCEDURES

5.1.0 En Route/Return operators are required to perform the following general tasks.

5.1.1 Monitor the progress of the simulated mission.

5.1.2 Coordinate (adjust arrival times) all RPV arrivals to the target and recovery areas.

5.1.3 Time-phase each Strike RPV such that it achieves its "original" ETA (assigned during flight plan generation) to each designated waypoint (S, H, T, B, R). To achieve a maximum number of hand-overs to pilot, some deviations are permissible (also see 5.6.1).

5.1.4 Time-phase RPV recoveries such that EW and Low Recce RPVs arrive at R in any order, Strike achieves original ETA to R, and the arrival interval of all RPVs is not less than 15 seconds apart.

5.1.5 Perform hand-offs to other operators when required.

5.1.6 Accept RPVs (on a passive basis) handed off by other operators.

5.1.7 Hand-back RPVs upon request from another operator.

5.1.8 Respond to RPV failures, e.g., by Destruct, Deploy Chutes, Switch in back-up navigation system, etc.

5.1.9 Reprogram (recycle) RPVs to replace RPVs that are lost due to malfunction, attrition, etc. Strike and Low Recce RPVs are replaced only if lost during En Route to target.

5.1.10 Manage RPV fuel.

5.2.0 ETA adjustment for an RPV is accomplished by the operator altering RPV velocity and/or RPV heading (i.e., increasing or decreasing RPV flight path distance). Reprogramming an RPV is accomplished by causing the replacement or support RPV to go to the new target area after it has completed its assigned mission. A replacement RPV must be of the same type as the lost RPV and must be time-phased with the remaining RPVs of the group. A group of RPVs consisted of a Strike, EW, Low Recce triad for RPV Study VII and a Strike, EW pair for RPV Study VIII. Additionally, a replacement strike RPV must be assigned to the same target as the lost strike RPV.

5.3.0 The pilot is required to perform the following general tasks.

5.3.1 Direct coordination of RPV hand-offs and arrivals to target and recovery areas during "dead-time" of en route and return phases of the mission.

5.3.2 Accept Strike RPVs from En Route/Return operators.

5.3.3 Switch into Video and Continuous Control modes when a Strike RPV is successfully handed-off.

5.3.4 Perform target acquisition and simulate line-of-sight target lock-on for weapon release (activate trigger switch).

5.3.5 Perform hand-back of a Strike RPV following the Terminal Phase.

5.4.0 Target detection and acquisition requirements were minimal during the Terminal Phase. This was due to the large number of repeated runs to the same targets and the small area of the terrain model. At the present time, the lack of significant detection and acquisition problems is not viewed as a serious deficiency. These simulation studies are concerned with the dynamic interaction of the major elements of mission phase integration, multiple RPVs, near simultaneous hand-offs, multiple operator interactions, etc.

5.5.0 A successful hand-off could occur (a Strike RPV achieves continuous control) only if the RPV was within a ± 1500 ft wide corridor on both sides of the flight path to the target.

5.6.0 There were a number of performance requirements which the RPV system was expected to achieve. These were prioritized for the operators. Operators were instructed that in order to achieve the criterion of highest priority, some accuracy might have to be sacrificed on lower priority items. Furthermore, each team (see 5.7.0) was allowed to employ its own strategy for meeting the criteria.

5.6.1 The general requirement in RPV Study VII was to deliver each Strike RPV to target with as many EW RPVs within a five nautical mile radius of the corresponding target as possible and followed 2.0 minutes +15 seconds later by a single Low Recce RPV. The major priorities of the RPV Study VII were:

5.6.1.1 Maximize the number of Strikes achieving target and achieving the criterion of maximum number of EWs within a 5 NM radius of target and a Low Recce fly over target 2.0 minutes +15 seconds later.

5.6.1.2 Maximize the number of Strikes achieving target with coverage by a maximum number of EWs within a 5 NM radius of target with slippage in the Low Recce criterion.

5.6.1.3 Maximize the number of Strikes achieving target with coverage by at least one EW within a 5 NM radius of target and also achieving the Low Recce criterion.

5.6.1.4 Maximize the number of Strikes achieving target with coverage by at least one EW within 5 NM radius of target and with slippage in the Low Recce criterion.

5.6.1.5 Maximize the number of Strikes achieving target with EW coverage but no Low Recce coverage.

5.6.1.6 Maximize the number of Strikes achieving original ETAs and minimize Strike lateral error.

5.6.1.7 Maximize the number of Strikes achieving target.

5.6.2 The general requirement in RPV Study VIII was to deliver each Strike RPV to target with as many EW RPVs within a five nautical mile radius of the target as possible. (The Low Recce type of RPV was eliminated in RPV Study VIII.) The major priorities of RPV VIII were:

5.6.2.1 Maximize the number of Strikes achieving target and achieving the criterion of maximum number of EWs within a 5 NM radius of target.

5.6.2.2 Maximize the number of Strikes achieving target with coverage by at least one EW within 5 NM radius of target.

5.6.2.3 Maximize the number of Strikes achieving original ETAs and minimize Strike lateral error.

5.6.2.4 Maximize the number of Strikes achieving target.

5.7.0 Operator teams were required to do their own planning and scheduling of RPVs. The planning was done at the start of a mission. Operators were provided with computer print-outs listing original ETAs to all waypoints for each RPV flight plan. Operators were also permitted to use electronic calculators or other devices of their own choosing.

5.8.0 The three targets for a given mission were chosen randomly from a set of twenty-seven targets located on the terrain model. The targets were in the form of small white disks easily identifiable on the pilot's video monitor. The pilot was provided with maps and photographs of the terrain model. It was the pilot's task to locate the three targets prior to performing the first strike and without the benefit of the terrain model. When not in the continuous-control/video-on modes of a Terminal Phase for an RPV, the pilot has access to closed circuit video from one of the En Route/Return CRTs. The display is on the same video monitor that provides the terrain video. This display provided the pilot with ongoing mission information, e.g., progress and ETA of a given RPV.

6.0 SPECIFIC OBJECTIVES AND SYSTEM PARAMETERS INVESTIGATED

6.1.0 The Objective of RPV Study VII was to evaluate RPV system capabilities to perform a simulated mission under the conditions and parameters described above and to investigate the effect of team composition (independent vs. pooled assignments) on RPV systems performance over a set of independent variables. The RPV system referred to here is strictly that system postulated by the RPV system simulation. In order to accomplish this objective, the same missions that were executed in RPV Study V were replicated with pooled constituted teams in RPV Study VII. As will be noted below, the same operators that performed in RPV Study V also performed in RPV Study VII, except that previously they had been members of independently constituted teams. Thus, the data base collected previously under RPV Study V provided the basis for comparison with the "pooled" condition.

6.2.0 Five independent variables of RPV system performance were varied in RPV Study VII (in order to replicate RPV Study V missions). Four of the variables involve timing parameters of data transmission. The RPV system is assumed to operate in an environment where data transmission over radio frequencies has to be shared with other users, so that a transmission time slot becomes available only on a periodic basis, and only then can data be transmitted. (An objective of RPV Study V was to obtain an estimate of what the timing values should be.) These five independent variables are listed here and are graphically portrayed in Figure 4.

6.2.1 Telemetry Data Transmission Time - When data can be received from an RPV (slot cycle times of 0.7, 2.1, 3.5, 4.9 and 6.3 seconds).

6.2.2 Command Data Transmission Times - When commands can be sent out to RPVs (cycle values same as above).

6.2.3 Call Delay for Modification/Window Displays - When an operator calls for a display, the display is delayed in accordance with a time factor (values same as above).

6.2.4 CRT Non-Immediate Information Update Time - Display frame time (2.8, 5.6, 8.4, 11.2 and 14.0 seconds).

6.2.5 Number of RPVs under system control (9, 15, 21, 27, and 33).

6.3.0 The values of the above variables were identical to those used in RPV Study V. The reason for replicating all the variables of RPV Study V was to study the effects of team composition on system performance. In RPV Study V, each En Route/Return operator was a permanent and independent member of one and only one team. In RPV Study VII, each En Route/Return operator was a member of two different teams, which approximates a condition where teams would be constituted at random from a limited pool of operators. The number of available operators and scheduling considerations precluded carrying out the completely random assignment of operators to teams.

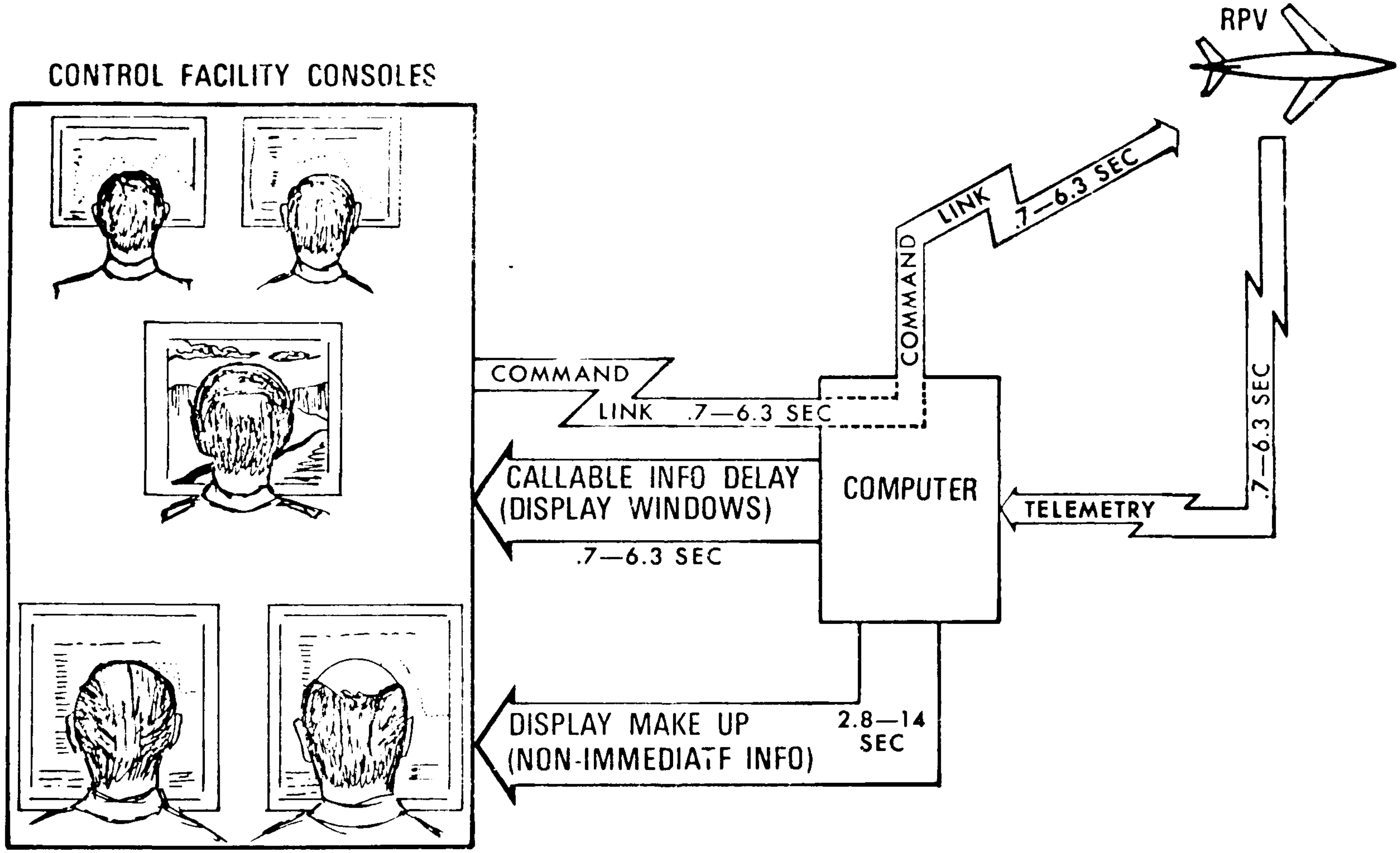

Figure 4. [illegible] RPV SYSTEM SIMULATION STUDY DATA LINK PARAMETERS

6.4.0 The five variables were varied in combination with each other according to a Central Composite/Fractional Factorial experimental design (Cochran and Cox, 1957). This type of design allows one to investigate a large, multivariate, experimental space by collecting a minimum number of observations. A single execution of the RPV system simulation (i.e., one simulated mission) constitutes one observation. The importance of, or interest in, the results of RPV Study VII lies more in the comparison of the results of RPV Study VII to those of RPV Study V, as opposed to the study of effects of specific variables. There were 32 observations obtained on each of four operator teams in RPV Study VII, yielding a total of 128 observations. Each observation required approximately 1 3/4 to 2 1/4 hours of execution time.

6.5.0 The objective of RPV Study VIII was to investigate individual operator and team size influences on RPV system performance. The RPV system referred to here is strictly that system postulated by the RPV systems simulation.

6.6.0 The make-up of the variables in RPV Study VIII was different from that used in all previous studies. As in several previous studies, this study too assumed that the RPV system operates in an environment where data transmission over radio frequencies has to be shared with other users, so that a time slot becomes available on a periodic basis, and only then can data be transmitted. The four timing parameters in RPV Study VIII were held constant as follows:

Telemetry Data Transmission Time: 3.5 seconds.

Command Data Transmission Time: 3.5 seconds.

Call Delay for Window Displays: 3.5 seconds.

CRT Non-Immediate Information Update Time: 8.4 seconds

Team size was one of the variables investigated in this study, there being teams of 1, 2, 3 and 4 En Route/Return operators, plus one pilot. Rather than varying the absolute number of RPVs, their ratio to operators was used as a variable. Because the program permitted a maximum of 35 RPVs to be simulated, the 10:1 ratio was not achieved exactly at the four operator team size but only approximated. All other ratios and team sizes were exact. There were ratios of 2:1, 6:1, and 10:1 RPVs to operators. These ratios maintained a constant RPV workload per operator across team sizes and within each ratio level.

7.0 OPERATOR TEAMS

7.1.0 Operators were obtained from universities in the Dayton, Ohio area. They were required to be undergraduates for program longevity purposes and to have at least a "B" grade point average. However, because many had been incoming freshmen at the start of the research program and there were occasional immediate needs, the grade requirement was sometimes relaxed. Teams were comprised of five operators (four En Route/Return operators and one Pilot) in RPV Study VII, while team size was one of the experimental variables in RPV Study VIII.

7.2.0 Individual operators acquired a minimum of 5 months training. All operators had completed this initial training, and had participated in one or more RPV studies prior to RPV Studies VII and VIII, so that they were considered to be highly experienced and skilled in handling simulated RPV missions. All operators had participated in RPV Study V. Pilots were given additional training (2 weeks) in instrument flight simulators, as well as controlling the camera over the terrain model. In addition, each team executed a number of practice missions before actual mission runs began. Formal data collection was started after an unanimous consensus of the teams that they were ready to proceed was obtained (Because of the complexity of the simulation, the operators were more knowledgeable about their tasks and procedures than the investigators. At the present levels of the state-of-the-art in systems research, it is virtually impossible to develop formal training criteria for "asymptotic performance," etc.)

8.0 RPV STUDY VII RESULTS

8.1.0 The purpose of RPV Study VII was to compare independent vs. pooled constituted team performance, thus the data analysis will be geared appropriately for that intent.

8.1.1 A table (similar to Table 1, Aume, Mills, et al., 1977) listing means and standard deviations for both RPV Study V (independent) and RPV Study VII (pooled) was prepared for 64 dependent variables. A comparison of the values disclosed that the means had an overall average change of 1.012% and the standard deviations had a reduction in magnitude of 9.43% from RPV Study V to RPV Study VII. To determine the significance of these changes, Chi square tests were conducted. For the means: 38 variables were better (toward improved average performance) in RPV Study VII and 26 were better in RPV Study V.

$$X^2 = \frac{(38-32)^2}{32} + \frac{(26-32)^2}{32} = 2.25 \text{ (d.f. = 1) and not significant.}$$

For standard deviations: 46 variables were better (lower) in RPV VIII, and 18 were better in RPV Study V.

$$X^2 = \frac{(46-32)^2}{32} + \frac{(18-32)^2}{32} = 12.25 \text{ (d.f. = 1) and significant at } < 0.01.$$

8.1.2 Since the above procedure may have violated the assumption of independence among dependent variables, an intercorrelation scan of dependent variables was performed starting with "difference between ETA and ATA at S waypoint" and using an intercorrelation cutoff value of 0.30. From this scan, 58 variables were retained (i.e., all intercorrelations were 0.30 and variances accounted for 10%), including the important variables of "proportion of Strikes successfully handed off to pilot" and "range from EW to Strike when Strike is at target." Repeating the Chi square tests for the 58 retained variables:

For means: 36 variables were better in RPV Study VII and 22 were better in RPV Study V.

$$\chi^2 = \frac{(46-29)^2}{29} + \frac{(22-29)^2}{29} = 3.38 \text{ (d.f. = 1) and not significant}$$

For standard deviations: 46 variables were better in RPV Study VII and 12 variables were better in RPV Study V.

$$\chi^2 = \frac{(46-29)^2}{29} + \frac{(12-46)^2}{29} = 19.93 \text{ (d.f. = 1) and significant at}$$

< 0.01.

From these results, it may be concluded that the overall mean performance, comparing independent vs. pooled constituted teams, does not change. On the other hand, the performance variability, on a team basis, exhibits a significant decrease.

8.1.3 Explanation of this observation can be sought in how individual operators contribute to inter-operator variability. In the case of the independently constituted teams, each subject contributes to only one team, and each team consists of different individuals. In the case of the pooled constituted teams, the same individual belongs to more than one team and so the contribution to those teams is the same. Thus, the variability in performance across pooled constituted teams relative to independently constituted teams is reduced approximately 10%. Average performance as measured by the means of the dependent variables appears to reamin unchanged. This latter result would be expected if one assumes that one operator's performance was stable and not influenced by team composition; an assumption that tends to be confirmed by the results of RPV Study VIII below.

9.0 RPV STUDY VIII RESULTS

9.1.0 For the study of effects of individual operators and the effects of team size on the performance of the simulated RPV system, certain important variables were selected for close scrutiny. The criterion for selection was that one could reasonably expect operator actions to have an influence on the variables, as opposed to a variable whose value is determined by program parameters and which is largely independent of operator actions. For example, RPV cross track error is to a large extent under the control of the automatic heading correction function. The following variables were chosen: Differences between ETA and ATA at target for strike RPVs; proportion of strike RPVs handed off to pilot; manual heading changes per strike RPV, attempted and transmitted; range from strike to EW RPVs with strike at target; and number of RPVs assigned to an operator at the start of each mission.

9.1.1 The results were reviewed and the following behavior of the variables were observed:

9.1.1.1 Difference between ETA and ATA at target for strike RPVs: The mean value for this variable was 4.41 seconds, with a range from 3.0 to 7.0 seconds. An analysis of variance (team size X RPV: Operator ratio X subjects) was performed on the data and the RPV: Operator ratio was the only factor found to be significant at $p < 0.01$ ($F = 5.189$, df = 2,72). From the plot shown in Figure 5, it can be seen that the difference decreases with increasing ratio; but, from a practical point-of-view, this tendency is very slight, approximately one second or less. It can also be seen in Figure 5 that team size did not have a significant effect on the dependent variable. This was also the case for individual operators' performance on this variable as a function of team size (i.e., the operator X team size interaction was nonsignificant).

9.1.1.2 Manual heading changes per stike RPV, attempted and transmitted: In both case, the data indicated a rather level performance over team sizes, and a slight decrease as the ratio of RPVs: Operators increased. An analysis of variance was performed (same as in 9.1.1.1) and disclosed that the RPV: Operators' ratio was significant variable (p 0.001, $F = 10.98$ df = 2,72). No other main effects or interactions were found to be significant. Attempted heading changes had a mean value of 1.91 and a range from 0.0 to 4.0. The behavior of this variable is understandable; as an operator acquires more RPVs to handle, the attention and actions devoted to any individual RPV would become less. The proportion of acceptable heading changes actually transmitted to those attempted did not exhibit any obserable changes.

9.1.1.3 Range from strike to EW RPVs, strike at target: Over the RPV: Operator ratios and team sizes, on the average, there was little change. Performance on this variable tended to be

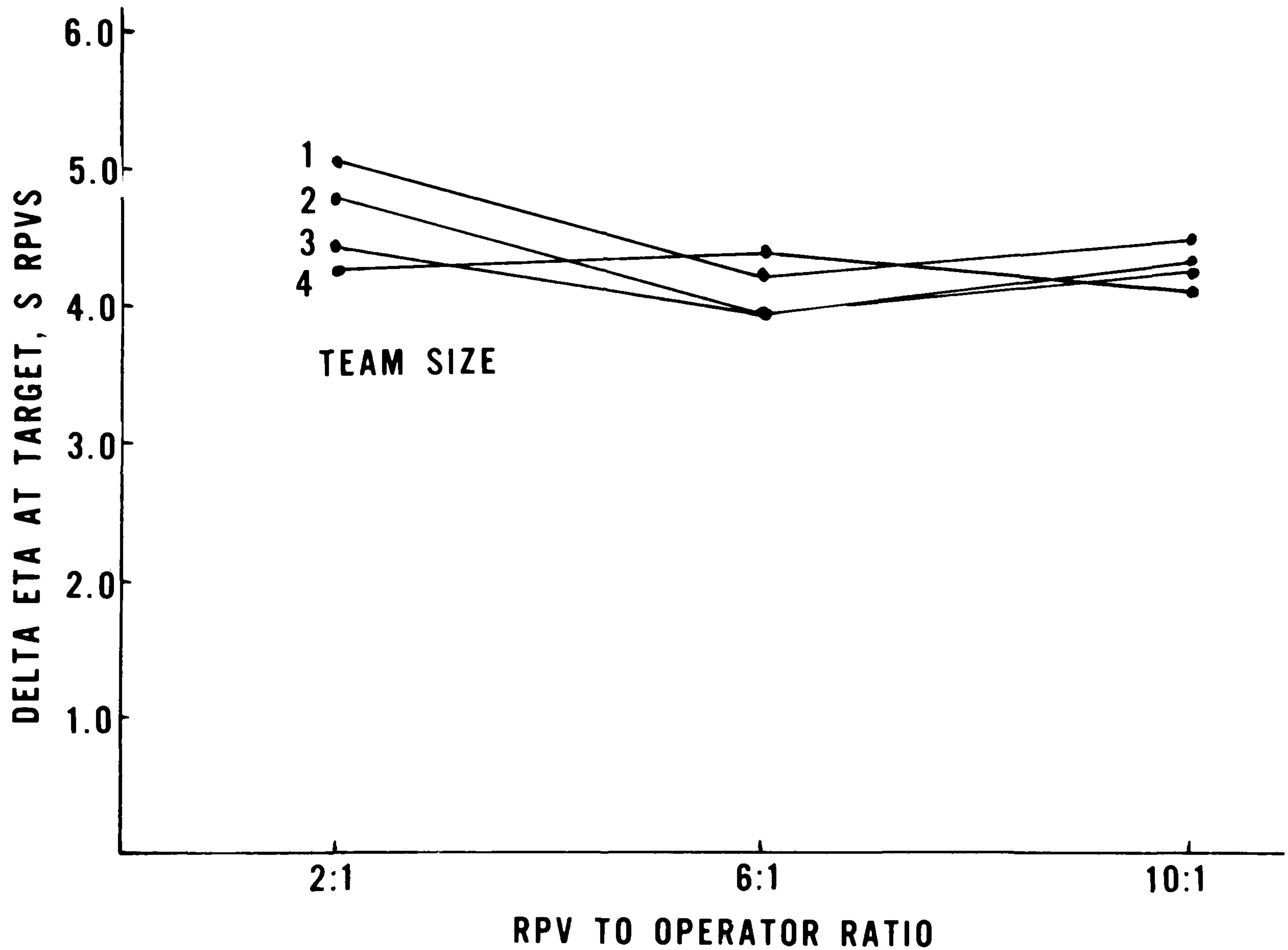

Figure 5. DIFFERENCE BETWEEN ETA AND ATA AT TARGET FOR STRIKE RPVs

quite erratic and was not conducive to a systematic analysis. The obtained performance was probably the result of shifts in EW RPV availability during real-time and as malfunctions occurred. The mean was 4.05 NM and the range was from 0.0 NM to 20.9 NM.

9.1.1.4 Proportion of strike RPVs handed off to pilot: The mean value of this variable was 0.89 with a range from 0.50 to 1.00. An analysis of variance (same as in 9.1.1.1) was performed. The RPV: Operator ratio was found to be significant (p 0.001, $F = 20.05$, $df = 2,72$) as well as team size (P 0.01, $F = 4.21$, $df = 3,72$). From the data, the following regression equation was computed: Proportion = 0.94497 - 0.02043 X Ratio + 0.02661 X T. size. A plot of this variable (Figure 6) indicates that the proportion is very close to unity at the 2:1 RPV: Operator ratio, and gradually drops off as the ratio is increased. However, there is less of a drop-off at the large team sizes. Such behavior could be expected, as the amount of actions to be taken by the operator increases with increasing ratio and for various reasons, some strike RPVs are not handed off. One of the reasons may be that some of the RPVs were lost during the En Route leg and thus were not available for handing off. The operator X team size interaction was found to be nonsignificant indicating that although this variable was affected by team size, individual operators' performance was not. This variable, as opposed to the previous, falls in the team-centered category because it involves coordination among the operators.

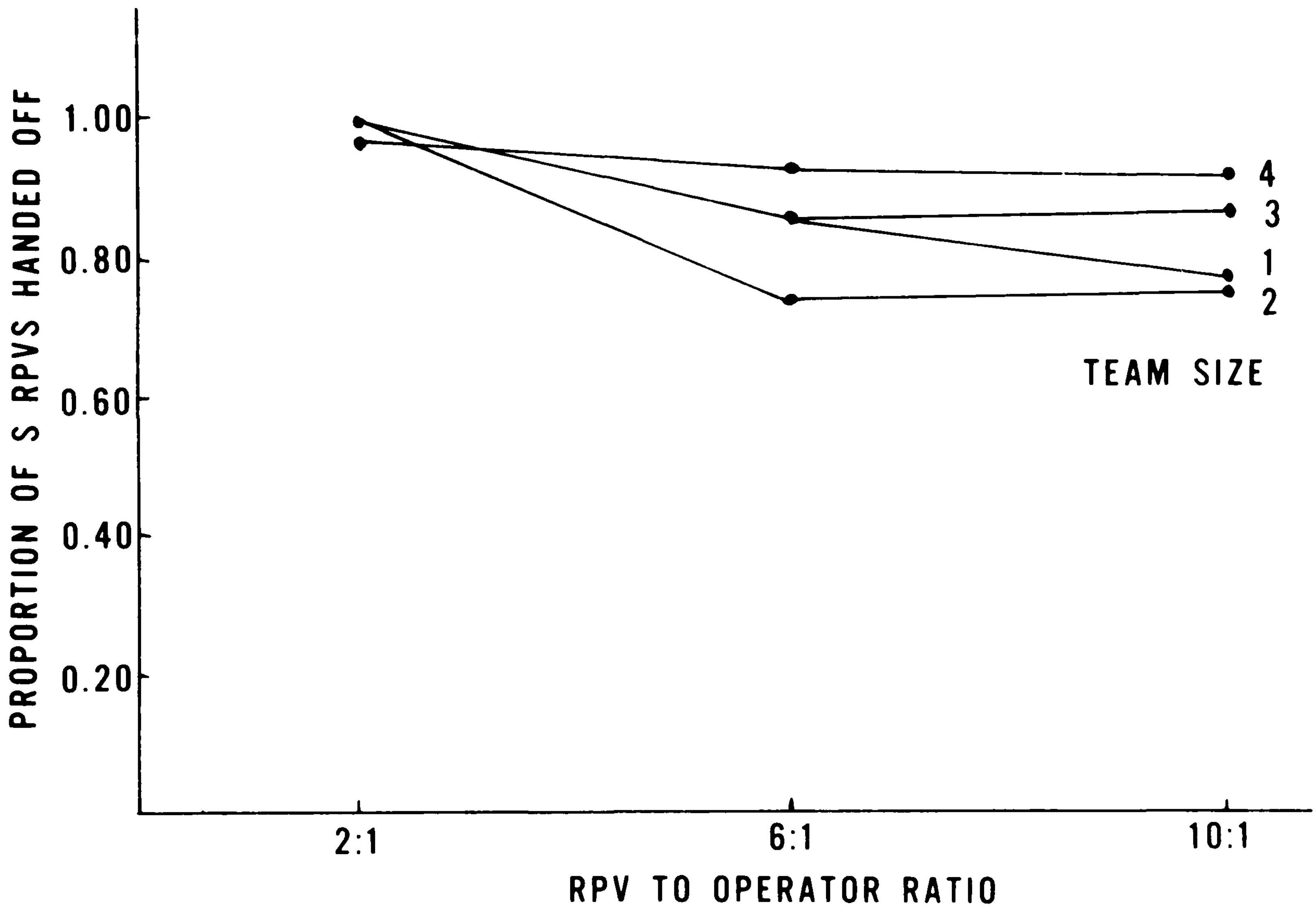

Figure 6. PROPORTION OF STRIKE RPVs HANDED OFF TO PILOT

9.1.1.5 Number of RPVs assigned to an operator, Strikes and EW: This variable was looked at more to establish what the operators had been doing rather than with a scientific interest. From the data, it became obvious that under 1-, 2-, and 3-person team sizes, each operator handled a subset of the RPVs consisting of both strike and EW types. Under the 4-person team, they apparently reverted to the division of labor as it had been practiced in previous studies in which one operator would handle strike RPVs at all three targets, and the remaining three operators would handle the support RPVs, each operator for a specific target. With a few exceptions, the values were either 1, 3, or 5 RPVs assigned which reflect the RPV: Operator ratios and the equal number of strike and EW RPVs.

10.0 CONCLUSIONS

10.1.0 Before going any further, two effects must be mentioned: The experience level of the subjects, and the nature of the system. To restate what was said in paragraph 7.0, the operators had accumulated a great deal of experience, each having participated in at least two RPV studies (and some operators even more) prior to RPV Study VII. Thus, they were highly knowledgeable and skilled in the operation of the RPV system. Second, it must be remembered that we are dealing with a system that is capable of performing completely automatically. It is possible for an RPV to fly from launch to recovery without operator intervention. Operator intervention is required only to accomplish the strikes on the target during the terminal phase; and it is at times needed to maintain systems navigation accuracy within prescribed limits and other prescribed experimental requirements.

10.2.0 According to the observed results and the previous considerations, the following conclusions can be made:

10.2.1 Experienced operators tend to maintain a highly stable, constant level of performance, as long as the system requirements do not become extreme such as might occur in the case of an unusual situation or requirement. Judging from the results, the workload that was imposed on the operators did not exceed their capabilities, and thus no distinct practical deviations from the performance levels were recorded either directly as a function of workload or indirectly as a function of decreasing team size. One area of interest here is to determine what constitutes an "extremity" or "rare event" and the impact on the stability of a system. The stability of performance also explains why average performance did not change in RPV Study VII. It can also account for the fact that large differences were not obtained between 3- and 4-person teams despite the fact that team strategies or operating procedures had been changed (see paragraph 9.1.1.5 and 10.2.3 below).

10.2.2 The results suggest that there are two classes of operator tasks involved in the system under investigation.

10.2.2.1 The first class can be referred to as "team-centered" tasks. These are tasks that involve some degree of coordination among operators and are exemplified by the variable "Proportion of Strike RPVs Handed Off to Pilot" (see paragraph 9.1.1.2). This variable is probably the only one in this system whose performance depends upon operator coordination or on a team-centered task. It was chosen for examination for this reason and was found to be the only variable that significantly improved in performance as team size was increased. However, even in the case of this variable, individual operator performance remained stable such that it was unaffected by team size. Apparently, the efficiency of performing the coordination function improved as team size was increased.

10.2.2.2 We have chosen to call the second class of tasks "Operator-Centered" tasks. Controlling a system using these tasks can be thought of as involving only parallel processing. The performance of one operator thus has a fairly simple, direct influence on the average performance of a team and is largely independent of the performance of other team members. This class of tasks is exemplified by the variables "Difference Between ETA and ATA at Target for Strike RPVs" and "Manual Patches Per Strike RPV, Attempted and Transmitted." When these variables were examined, it was found that there was no influence of team size. This result, in addition to the fact that individual operators did not exhibit any systematic differences in performance over team size, led us to conclude that operator-centered tasks are not only those that work in parallel with other operators' tasks but are also highly stable and, thus, well-trained.

10.2.3 Since none of the variables examined exhibited significant differences among operators, it can be concluded that there were no practical differences in performance between male and female operators. (NOTE: This has been a consistent result throughout all of the RPV system simulation studies.)

10.2.4 Division of labor was practiced at the 4-person team size, but not at the smaller sizes. This cannot be construed as the effect of any variable - the operators could have been instructed not to do it just as easily. The division of labor with 4 operators is, undoubtedly, a carry-over from previous studies (although it is possible that the carry-over was perceived as necessary). It consisted of one En Route/Return Operator handling all strike RPVs, and each of the remaining three operators handling the support RPVs at one of the three targets. With a team size of one operator, there can be no division of labor and the operators must have decided that it would not be useful (the activities at 3 targets are to be distributed among the support operators) or efficient to practice it at 2- and 3-person team sizes.

10.2.5 Variability in the observed variables is sometimes extreme and is probably due to the variability of dynamic events, (e.g., the loss of an RPV due to a malfunctioning subsystem). The fact that unpredictable events can occur in a system over time is another reason why systems are a difficult object to study.

10.2.6 The general conclusion from the foregoing is that for the purposes of modelling and simulation of operator-centered (highly-trained, parallel-processing) tasks, team size appears to have little influence. This obviously may not hold for what can be termed team-centered (coordination or decision making, serial processing) tasks, which suggests a course of action for future research where one might establish the delineation points among classes of tasks. This should be accomplished in terms of the onset of significant changes in performance, so that good definitions of each class of tasks can be developed in operational terms. Also, it appears that estimates of individual performance on operator-centered tasks based on literature studies may be adequate as input data to system models and fast-time simulations.

11.0 FUTURE PLANS

11.1.0 It was noted that the workload level on the operators did not appear to be excessive. In an attempt to quantify this statement, or at least to get a better insight into this behavior phonomenon, RPV Study IX will be conducted wherein a secondary (or auxiliary) task will be introduced into the RPV system simulator and the performance of the operators on it will be measured. The primary task will be controlling a standard RPV Study VII type of mission with strike and EW type RPVs. The auxiliary task will consist of maintaining Low Recce type RPVs on course with manual course corrections.

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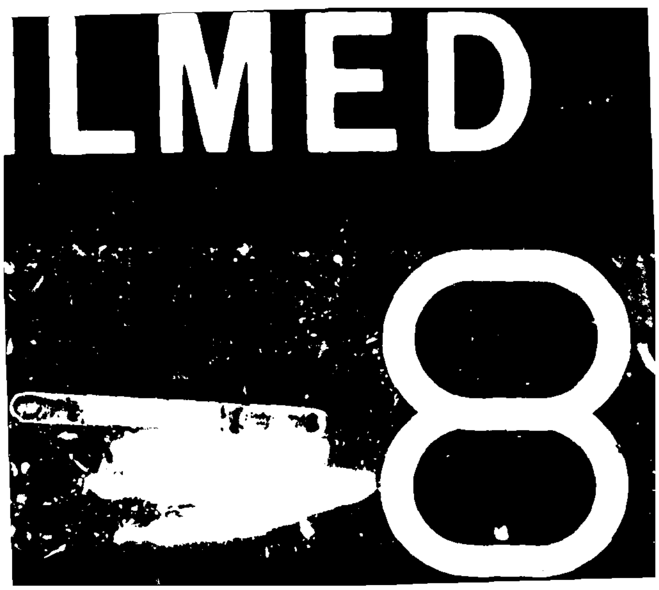
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